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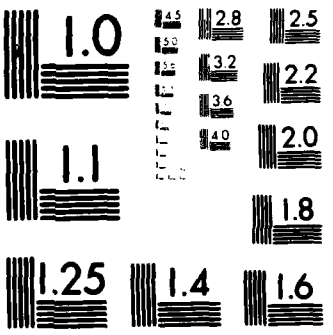

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Optics '86: Four Western European Countries Review Recent Achievements

Paul Roman

June 27, 1986

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The conference in The Hague covered a very broad field of topics, including optoelectronics. This review highlights presentatoins on nonlinear optics, optical data storage and optical computing, image processing, and novel optical materials.

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OPTICS '86: FOUR WESTERN EUROPEAN COUNTRIES REVIEW RECENT ACHIEVEMENTS

1 INTRODUCTION

The West German Society for Applied Optics, the Netherlands' Optical Committee, the Optical Group of the UK's Institute of Physics, and the French Optics Society joined hands in organizing a medium-sized, unhurried, pleasant conference, "Optics 86," in The Hague, 21 through 24 May. The chief organizing sponsor was the Dutch foundation "Quantoptica." Funds were contributed by sources from the Netherlands, and by the European Physical Society. The meetings, held at the Netherlands Congresscenter, were attended by 300 participants, divided about equally among the four organizing countries (but Dutch and German was predominant in the corridors). A few scientists came from Spain and Poland, and there were a few overseas visitors as well. There were 10 invited talks (40 minutes long) and 75 contributed papers (20 minutes each). The contributed papers were given in two parallel sessions. There were also 16 poster papers with their usual distracting effect. The meeting was accompanied by a small, but excellently organized and displayed exhibition by Western European firms of laser, optic, and optoelectronic equipment. (Unfortunately, though, no catalog is available.)

The talks were grouped into the following sessions:

- Holographic and speckle methods (two sessions)
- Imaging (two sessions)
- Image processing (two sessions)
- Optical materials
- Optical metrology (two sessions)
- High-speed phenomena
- Instruments and optical components
- Theoretical optics
- Vision

The titles of these sessions are somewhat misleading, and there was some overlap. In fact, I have selected topics for reviewing which came from different official sessions but are better understood in context when put together. Upon request, I will be glad to supply the abstracts of most talks in any given session. A list of participants is also available.

I shall review topics in the following fields of research:

- Nonlinear optics
- Optical data storage and optical computing
- Image processing
- Optical materials

2 SELECTED TOPICS

Nonlinear Optics

In a presubmitted written address, W. Sibbett (University of St. Andrews, Scotland) reviewed the origin and the major features of intensity-dependent self-phase-modulation effects in fibers. These effects arise when pico- (or, still better, femto-) second light pulses are made to propagate within the confined core section of a single-mode optical fiber. One important (and quite well known) practical exploitation of these nonlinear effects is the fiber-based temporal compression of laser pulses. Two cases were distinguished by Sibbett: normal, and anomalous group velocity dispersion. Less familiar applications are: stimulated Raman scattering or frequency mixing in fibers.

P. Tapster (Royal Signals and Radar Establishment, Malvern, England) represented a well-known group of researchers who have been involved for some time in pioneering work in the area of quantum optics. The work reported by Tapster concerned the best (so far reported) generation of light which has a sub-Poissonian photon distribution. The simplest definition of a sub-Poissonian distribution is given in terms of the Fano factor, $F=(\langle N^2\rangle-\langle N\rangle^2)/\langle N\rangle$. For a Poisson distribution this is equal to 1 (and for most practical light sources, $F>1$). A sub-Poisson distribution corresponds to a value of $F<1$. (An equivalent definition may be given in terms of the second-order photon number correlation

N(2), which, for a Poisson distribution, is also equal to 1.) The obvious importance of sub-Poisson distributed light is that it implies a drastically reduced noise level, particularly important for applications where observations must be made with very low light intensities. The Malvern scientists produced sub-Poissonian light by using parametric down-conversion of UV light from a He-Cd laser in KD*P, with feedback to an optical dead-time shutter, and with the addition of a fiber-delayed optical gate. The output consisted, as expected, of more-or-less equally spaced (i.e., anti-bunched) photons, which implies a sub-Poissonian distribution. The researchers actually measured the second-order correlation; to get good data, the experiment had to be run for 34 hours. The theoretically predicted value of N(2) was 0.83; the experiment (after correction for photodiode-detector dark, current was applied) yielded the value 0.87. The corresponding Fano factor was 0.9. Even though this is the "best" sub-Poissonian light source ever achieved, the output (which is, by the way, quite weak--2000 photons/s) can not be used for practical purposes. But the researchers feel confident that, within a foreseeable time, they will achieve F=0.5.

Several talks in the area of nonlinear optics were scheduled for French research groups. Because of a Belgian railway strike, the scientists failed to arrive in time. This caused rescheduling and confusion; nevertheless, since good written summaries were available from both this and another conference, I can give a report on the main points.

The Institute of Theoretical and Applied Optics (Orsay, France) communicated an exciting development: the first experimental observation of solitons in the visible range. The rank-3 solitons were generated by a passively mode-locked ring-configuration dye laser at 610 nm. The evolution of the pulse autocorrelation function during the soliton period was recorded successfully, and the period was found to correspond to about 2400 cavity roundtrips. It seems that any pulse produced by their laser system has soliton character. The practical relevance of the work is that the behavior of sufficiently high-order solitons offers new possibilities for intracavity pulse compression.

The cooperation between the same institute at Orsay and the Solid State Chemistry Laboratory at Bordeaux led to two, closely related papers. These were concerned with the measurement and experimental utilization of various nonlinear properties of $Bi_{12}SiO_2$ (BSO) and $Bi_{12}GeO_{20}$ (BGO) crystals. These are, primarily, new photorefractive materials which also have high photoconduction. The French scientists first studied the large nonlinearities, which can be induced with either continuous or pulsed laser beams. The diffusion length of the photo-excited carriers and the density of trap sites have been measured by an analysis of the transient behavior of the photo-induced grating. Subsequently, the researchers studied the influence of shallow traps on the conduction process and on the kinetics of the photorefraction effect. Femtosecond laser pulses were used to measure the rise-time of the phase grating induced in the crystals by a two-wave mixing process. This study allowed an estimation of the free charge-carrier mobility. Experiments have been conducted with both undoped and Fe-doped samples. Indications for optimization of the photorefractive effects were established. Of course, the practical importance of such studies lies in the hope that appropriately chosen materials will find effective applications in optical data processing, phase conjugation mirrors, and laser beam steering.

One more talk in the area of applications based on nonlinear processes caught my attention. H. Klumb (Technical University, Darmstadt, West Germany) described the first experimental realization of a phase-conjugate resonator (PCR) with high gain which is capable of transmitting large image fields. The ultimate goal of this research is in the area of applications for image processing, but the basic physics is equally

fascinating. As Klumb explained, an active coherent optical feedback system is a ring-arrangement where, in one arm, a coherent image amplifier is placed. (In one of the other arms filters and other optical elements can be placed. The outcoupling, after many roundtrips, proceeds through the one of the four mirrors which is semireflective.) In the Darmstadt proposal, the amplifying element is a phase conjugating mirror (PCM), based on four-wave-mixing in a photo-refractive $BaTiO_3$ crystal. Klumb gave three reasons why a PCM is particularly suited for incorporation in a feedback system, then proceeded to explain the working of the PCR, which is formed by a ring cavity (130-cm roundtrip path) with the PCM in the forward path. He pointed out that this PCR is self-imaging. The coherent light source used in the experiments was a conventional 150-mW Ar ion laser. The transmission properties of the system were discussed in some detail. Finally, Klumb told us that self-oscillation has been found to occur; i.e., oscillations developed by usin only the two pump-beams (no signal). These arise from the self-induced gratings in the crystal. Further plans for extension of the experiment into a 4f imaging system were indicated by the speaker.

Optical Data Storage and Optical Computing

Whereas optical recording technology is, at present, a field of more commercial use (entertainment industry) than of scientific or military interest, the assessment of its role is likely to change soon due to the advent of erasable, RAM compact memory disks. In addition, even the perfection of more conventional compact disk ROM or "mega-documentation" recording involves a challenging interplay of advanced micro-optics, optoelectronics, and materials sciences. For these reasons, the invited presentation by G.E. Thomas (Philips Research Laboratories, Eindhoven, the Netherlands) aroused considerable interest. He first summarized the current state of the art, based on laser-caused hole-making or ablation in suitable materials and reading by interferometry. He reported that, by employing diffraction-limited focusing optics, it is now possible to record data with rates over 20 MHz, and to achieve a data density better than 1 bit/μm^2 (corresponding to about 10^{11} or more bits/record). One of Philips' contributions in this area is the development of miniaturized, replicated aspherical-optics lenses (made of glass, with nonspherical contours on two sides of a spherical bead). The second part of the talk reviewed current experiments with erasable recording systems. Two possibilities were explored: systems based on materials that suffer a suitable phase change upon laser heating and systems based on magneto-optics. In the first case, instead of burning a hole, just enough heat is applied to transform spots on a polycrystalline material into amorphous blobs (which have different reflectivity). Erasing is achieved with a milder laser heating (for which a separate laser is used), which leads to recrystallization. The best materials for fast erasibility yet long-term stability were found to be TeSeSb alloys. Erase times less than 1 μs are easily obtained, and the most recent combination leads to 150-ns erasing speed. The alternative (magneto-optical) approach, also successfully tried at Philips, starts by using a premagnetized film on a substrate, into which magnetic domains of alternating (antiparallel) orientation are introduced during recording by the application of a constant magnetic field (produced by a small coil) and small-spot laser heatings of the film. The small (less than 1°) change in the polarization of the light reflected from adjacent magnetic domains on the film is detected by separating the polarizations with a halfwave plate; the two beams then are detected by separate photodiodes and the difference-current is measured. Erasing with a magnetic field is, of course, a trivial matter. The best materials so far found for this recording method were GaTbFe alloys.

There were several papers related to optical computing, but they did not

deal with the usual optoelectronics or quantum optics aspects of the subject. K.-H. Brenner (University of Erlangen-Nürenberg, Erlangen, West Germany), for example, talked about the idea of using a new kind of logic system for digital optical computing and its possible optical realization. The system, called symbolic substitution, is put forward in contradistinction of Boolean logic. Brewer asserted that this logic system, which also includes spatial information in the coding, takes advantage of the special opportunities rendered by optical signal processing, thus being more suitable for future optical computers than would be the optical initiation of electronically performed Boolean logic systems. Whereas Boolean logic systems use a state vector as an input and produce a state output, the proposed symbolic substitution system has, both for input and output, a state pattern (such as a two-dimensional arrangement of, say, "black" (zero) and "white" (one) squares. The optical implementation (coding) of such a state pattern might be done by intensity, by positional coding, or by polarization coding. Brenner advocates the latter. A black square is represented by a square of light throughput via a mask with, say, horizontal polarization, whereas a white square corresponds to vertical polarization. The major advantage of this coding is that it is easily changeable and absolute (does not involve probabilities). Examples for manipulations of such coded logic state patterns were given, not only for the case of an arithmetic processor but also for a Turing machine, thus illustrating, in principle, the universal applicability. More details of this research effort will be given in a paper by Brenner and A. Huang, *Applied Optics*, (in press).

J. Weigelt (also from the University of Erlangen-Nürenberg) reported on her work done with A.W. Lohman on demonstrating (by nonrealtime laboratory model experiments) a digital optical adder, based on spatial filtering. Primary logic operations (used in an adder, for example) are of course nonlinear, and therefore their optical realization is not straightforward. The Erlangen scientists used their method of spatial filtering, called theta modulation, for encoding the binary data. In this approach, the logic states of two-dimensional input signals are realized by a grating structure. A zero in a pattern may be represented by a horizontal square and a one by a vertical square of grating patterns. The filtering is done in the Fourier domain, simply by inserting a lens and a mask with appropriately placed holes in it into the light that passed the gratings (the holes correspond to the code). The filtering of the output of Object 1 is followed by the insertion of Object 2, and a second filtering yields the output. This is the basic design; of course, serial combination of many objects ("addends") is no problem, and one could even arrange for inputting two-dimensional arrays of objects ("numbers")--thus allowing for parallel processing each having many additions of many addends. In the simplest experiment, two illuminating beams (under a slight angle to each other) were used on a system consisting of four objects. The two beams corresponded to the simultaneously functioning sum-and-carry readers. The beams were recombined by small prisms (on plates put into the light train). This was, of course, a half-adder system. The researchers also succeeded in building a model experiment for a full adder, in which case they needed two parallel beamlines, but these were actually combined (by additional prisms) into one line. In essence, the proposed system is a single-instruction multiple processor, and many extensions can be imagined. But I think that the way from precoded gratings to the realtime system (presumably using instantaneous hologram gratings) will be long and bumpy--as will all developments leading to the all-optical computers of the future.

Image Processing

The keynote address, mostly tutorial in its scope, was given by I.T. Young (Delft Technical University, the

Netherlands). He emphasized that it is necessary in this area to distinguish between image enhancement, image restoration, and image analysis. (He gave an amusing example concerning the distinction between the often confused concepts of enhancement and restoration: You set the controls of the family TV set to "restore" with great accuracy the test pattern transmitted by the station, but when you come home in the evening, you find that the family messed up all your settings--they wanted an enhanced, not a correctly restored picture of Mickey Mouse!) Significant advances have been made recently in all aspects of digital image processing. Design techniques have matured to a point which permits the generation of optimal two-dimensional (Wiener) filters. However, it has also been recognized that linear filters have severe limitations, and this led to the development of nonlinear filtering techniques. One particular example is the variance (or median) filter. Here the value associated with each pixel is replaced by the median value associated with the eight neighboring pixels. Other nonlinear filters are of types termed "percentile" and "morphological." The speaker illustrated how a median filtering process can produce strikingly superior results compared to an optimal linear filtering. In the remainder of his talk, Young pointed out that traditional concepts are inadequate when the goal of processing is analysis (i.e., measurement) rather than simple filtering. He concluded by quoting recent results concerning the relationship between the measurement accuracy, the sampling frequency, and the parameter coding.

Because of its obvious potential in battlefield and surveillance applications, I will review one more talk in the area of optical image manipulation. It is the recent research of A.W. Lohmann (University of Erlangen-Nürenberg), which was reported by a former student, B. Wirniker. The research concerned itself with image restoration when all one has to start with is a series of images of the same object, badly distorted by photon noise, turbulence, unknown shifts, and unknown rotations. Typically, such situations arise if one wants to detect, at low light level, a randomly moving object or an object that is observed sequentially at randomly changing angles. Customary power-spectrum studies will not be adequate. Lohmann proved that third-order correlations are a powerful method of approach in these cases. The argument goes as follows. Suppose a large set of poor images $I_n(x)$ of an object have been collected. Then calculate the triple correlation:

$$I_n^{(3)}(x,y) = \int I_n(x') I_n(x'+x) I_n(x'+y)\,dx.$$

(Note that, unlike the case for the second-order autocorrelation, the number of variables gets doubled.) Now calculate the Fourier transform, $I^{(3)}(\nu_x, \nu_y)$, which is called the "bispectrum" of the object. It is easy to see (and quite crucial for the applications) that the bispectrum is shift-invariant (i.e., insensitive to the object's position changes). It can be proved that from the bispectrum the Fourier phase of the object can be retrieved (except for the zero and first-order Taylor coefficients). Thus, in a sense, triple correlations go some way toward the solution of the old problem of phase retrieval. Furthermore, one can also average the set $I_n^{(3)}$ to obtain $I_o^{(3)}(x,y) \approx \langle I_n^{(3)}(x,y) \rangle$. Lohmann showed that this quantity allows for the computation of the object, in the sense that it determines the image relative to the average position; i.e., it yields $I_o(x-\bar{x})$. Another detailed study led to the following result. Suppose that, with respect to a fixed background, the observations yield the shifted images I_n plus the background B, or the shifted images times the background or a combination. It can be shown that

$$I_n^{(3)}(x,y) \rangle = I_o^{(3)}(x,y) + B^{(3)}$$

for the first case, and similar expressions hold for the second and third contingency. This is very surprising because the formation of the triple

correlation is, of course, a nonlinear operation. While triple correlation techniques have much to recommend them, there are also drawbacks: $I_n^{(3)}$ is sometimes very small, and therefore data storage and processing becomes difficult. But powerful computers can compute objects by the above method within a few minutes, even if ideal conditions are not met.

Optical Materials

In optical materials I will review only the two invited talks because the contributed papers were concerned mostly with the measurement of optical characteristics of specific materials.

J. Petzold (Schott Glass Company, Mainz, West Germany) gave a comprehensive review of developments in the past 10 years in the area of materials science which were concerned with the need inspired by key technologies for better and more exotic optical materials. The review comprised glasses, glass ceramics, crystals, metals, and organic and composite materials for optical use, but did not touch upon items such as new solid-state laser hosts or integrated optics components.

The talk consisted of four parts. The first part, on materials for refractive optics (classic glasses, plastics, new glass composites) emphasized especially unusual achievements, such as the development of very high refractive index ($n \approx 2.4$) TeLa-oxide composites. Fluoride glasses were also discussed, and Navy scientists may be pleased to learn that Petzoldt specifically quoted with admiration the very recently published achievement of Dr. Tran's group at the Naval Research Laboratory (according to the speaker, loss less than 0.7 dB/km was achieved there). Another interesting point made in this part of the talk was the brief discussion of organic materials that have optical nonlinearity characteristics up to 3000 times larger than that of quartz.

The second part of the talk reviewed briefly what the speaker called "the world's biggest optics experiment," i.e., the design and fabrication of optical components for the giant NOVA laser system at Livermore. He made the interesting point that, at the YAG laser wavelength, the almost insurmountable problem is bulk damage in windows. This is caused by even the tiniest admixture of Pt particles (which come from the crucible). Surface damage is not so difficult to control; suitable coatings can be developed, given sufficient funds.

The third section of the talk partly overlapped the first: it was concerned with optical fibers, but special attention was given to fabrication methods.

The last part of the talk addressed materials for reflexive optics, especially for giant telescopes. (A point in case is a recent 10-m-diameter mirror which is built of a material with a thermal expansion coefficient of $10^{-9}/C°$). In the area of such applications, Petzoldt emphasized the breakthroughs in glass ceramics, leading, for example, to the material called Zerodur.

The talk was enlivened by illustrations drawn from the experiences of Schott's pioneering establishment.

The second invited paper, given by M.O. Lidwell (Pilkinstons Ltd. and Barr & Stroud Ltd., UK) discussed materials for infrared optics, mostly lens systems applications. The talk was neatly divided into analysis of mid-IR single band (8 to 13 μm) materials, multispectral materials (0.4 to 12 μm), and dual-band components (3-μm and 12-μm windows).

For the 8- to 12-μm range the typical (and, in the speaker's opinion, so far the most promising) material is germanium. It has a high index of refraction and low dispersion; it is hard and strong, and can be easily given protective carbon coatings. Lidwell's firm now fabricates single crystals up to 260-mm diameter; for larger components, polycrystalline construction must be used. But Ge has also disadvantages: temperature shift of the focus of Ge lenses, transmission loss at higher temperatures, thermal runaway, difficulties in making achromatic systems. Hence, if

problems near 13 μm (and beyond) are to be fully mastered, there is serious need for new ideas.

In the multispectral class, diamond, alkaline halides, PbF_2, ZnSe, and ZnS were suggested by Lidwell as possible candidates of diverse merits. He called attention to recent advances in chemical vapor deposition techniques which facilitate greatly the manufacturing of ZnS components.

For the dual band materials, the pros and cons of doped GaAs, CdTe, chalcogenide glasses, and rare earth ternary sulfides (such as GaLaS) were reviewed.

The talk concluded with the discussion of both materials-science and engineering choices for the design of achromatized and athermalized lens systems. There was also a brief discussion of IR window materials: their proper choice and their relative merits and shortcomings, depending on applications. Special attention was drawn to the new oxide (such as spinel) and oxinitride ("alcon") crystals for IR windows.

3 CONCLUDING REMARKS

Despite the fact that an alarmingly large number of talks had to be cancelled for a variety of reasons, this was a fine and successful conference. The atmosphere was conducive to person-to-person interactions; the pace was relaxed. Technical developments dominated, but there was also plenty of good basic science. One cannot expect a conference on optics to be "all-comprehensive" but, despite the noticeable lack of some areas (micro-optics, adaptive optics, integrated optics, laser sources and detectors for optics research, etc.), the meeting covered very wide ground. I found it particularly encouraging that it was the outcome of a four-nation cooperation which, in addition, also attracted scientists from other countries.

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